



X-ray testing Constellation-X optics at MSFC's 100-m facility



Steve O'Dell, Mark Baker, James Carter, Dave Content,
Bill Davis, Mark Freeman, Paul Glenn, Mikhail Gubarev,
Jason Hair, Jeff Kolodziejczak, Bill Jones, Marshall Joy,
Jeff McCracken, Giriraj Nanan, Scott Owens, Rob Petre,
Bill Podgorski, Brian Ramsey, Timo Saha, Jeff Stewart,
Doug Swartz, Will Zhang, and Galen Zirnstein

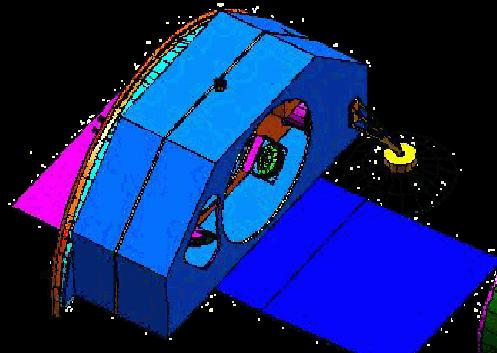
NASA Marshall Space Flight Center (MSFC)
NASA Goddard Space Flight Center (GSFC)
Harvard-Smithsonian Center for Astrophysics (CfA)
Bauer Associates
Universities Space Research Association, MSFC
Swales Aerospace, GSFC



Constellation-X design



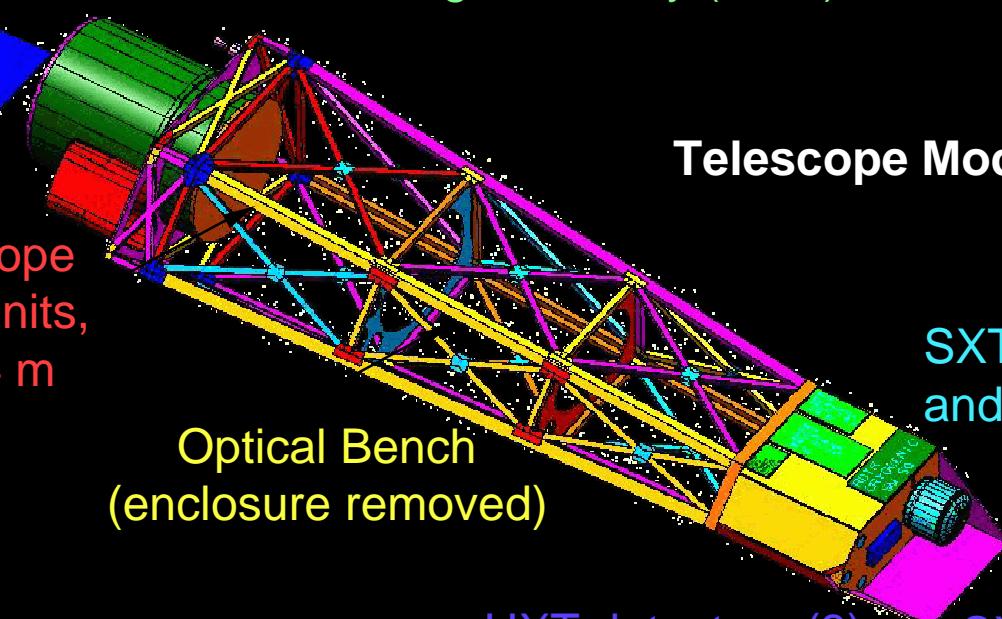
Spacecraft Module



Spectroscopy X-ray Telescope (SXT) optics — $F = 10\text{ m}$, $D = 1.6\text{ m}$ — and Reflection-Grating Assembly (RGA)

Telescope Module

Hard X-ray Telescope (HXT) optics — 3 units, $F = 10\text{ m}$, $D = 0.4\text{ m}$

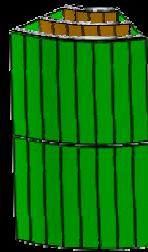




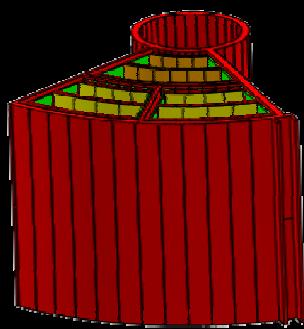
SXT development



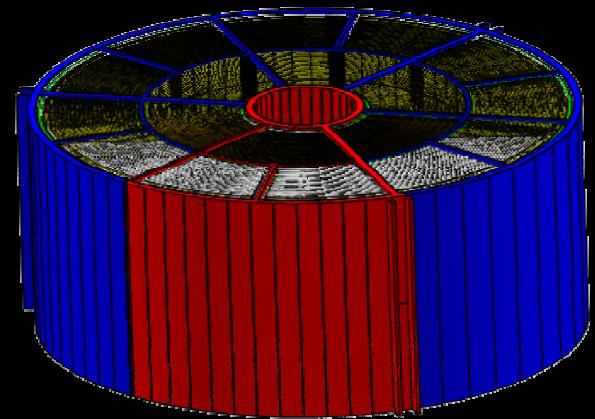
Engineering Unit



Prototype Unit



Flight Unit



Subscale inner module

- 8.4-m focal length
- 0.5-m diameter
- 1-3 mirror pairs

Flight-scale assembly

- 3 modules (2 outer, 1 inner)
- 1.6-m outer diameter
- 3-9 mirror pairs / module

Flight assembly

- 18 modules (12 outer, 6 inner)
- 1.6-m outer diameter
- 170-230 mirror diameters



MSFC optics test facilities



XRCF



100-m facility

- X-Ray Calibration Facility
 - 530-m long
 - Utilization
 - *Einstein* (HEAO-2) testing before facility renovation
 - *Chandra* (AXAF) calibration
 - NOAA SXI, Con-X, Solar-B
 - JWST cryo-optical testing
- Stray-Light Facility
 - 100-m long
 - Utilization
 - Originally stray-light testing
 - X-ray interferometry, etc.
 - Hard x-ray (e.g., HERO)



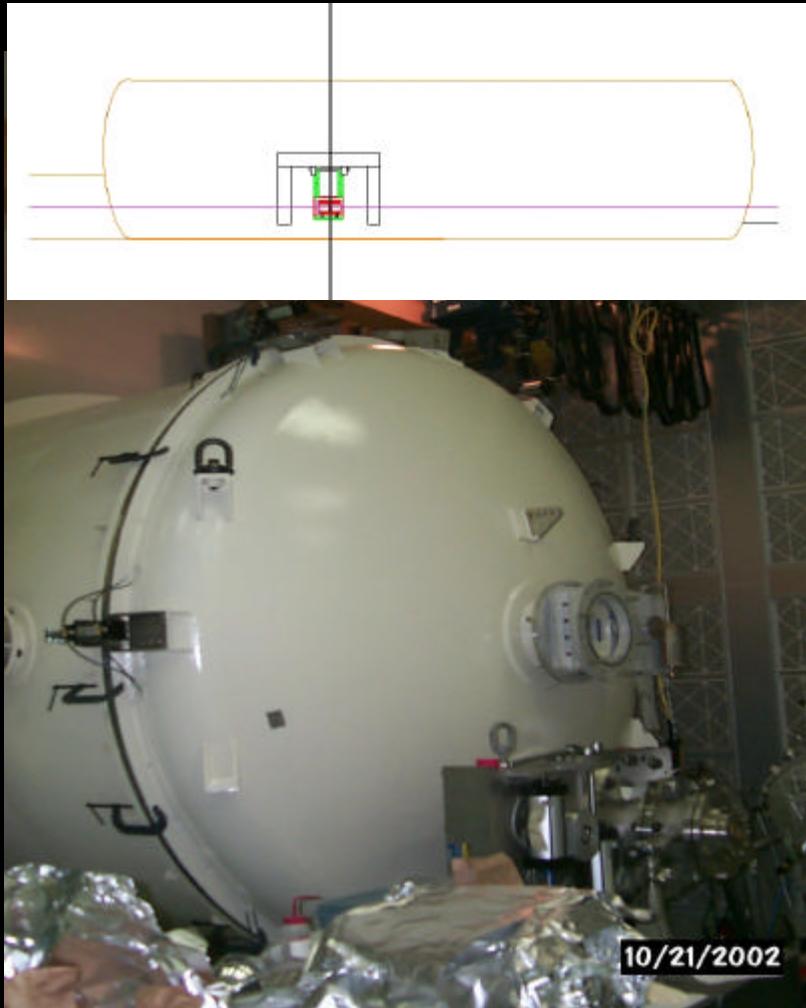
Test system for 100-m facility



	6-DoF subsystem <ul style="list-style-type: none">• Structure• Mechanisms• Encoders• Controller• Control computer• Cabling	Optic subsystem <ul style="list-style-type: none">• OAP2 (GSFC)• Reference flat• Mech. I/F (SAO)• Aperture (SAO)• Heater (SAO)• Thermal control	
Source subsystem <ul style="list-style-type: none">• Manson source• Target anode• X-ray filter• Blocking filter	Facility subsystem <ul style="list-style-type: none">• Tube and chamber• Vacuum pumps and facility power• Feed-throughs, LAN, etc.• Rail system and prep platform	CCD subsystem <ul style="list-style-type: none">• Camera & cooler• Controller• Control computer• Data acquisition	
		Data subsystem <ul style="list-style-type: none">• Image data (FITS)• Analysis S/W• Analysis computer	



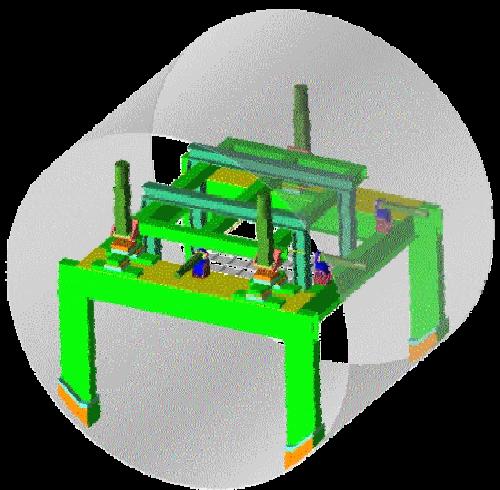
100-m facility chamber



- Dimensions
 - Large test chamber
 - 3.0-m (10-ft) diameter
 - 12.2-m (40-ft) long
 - Extension available through gate valve
 - Guide tube
 - 1.2-m (4-ft) diameter
 - 89.3-m (293-ft) long
- Disadvantages for testing
 - Guide tube at bottom
 - Must suspend large optics
 - No thermal control
 - Must control test-article T



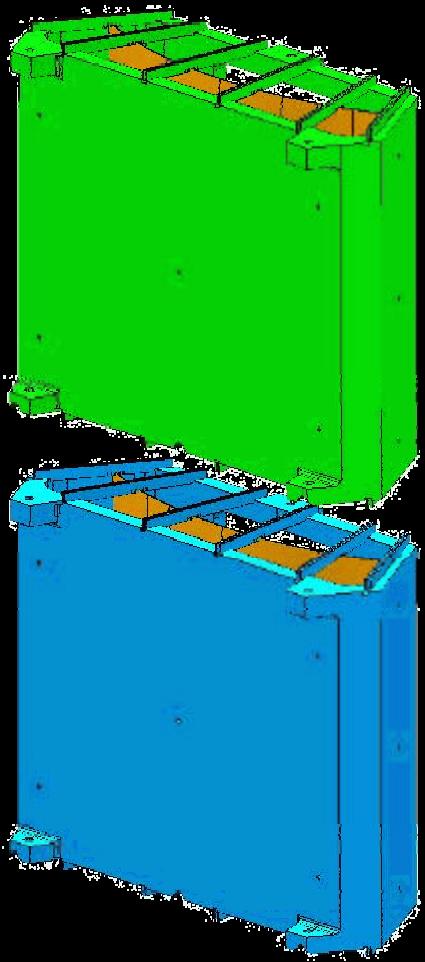
6-DoF optics mount



- Positions test article
 - 3-DoF translation
 - ± 75 mm, 25- μm resolution
 - Pitch and yaw
 - $\pm 3^\circ$, 5-arcsec resolution
 - Limited roll
 - Control system
 - Actuators and encoders
 - Electronics rack
 - LabView™ control software
- Structure and components
 - Supports article from above
 - Can hold SXT flight module
 - Contamination issues



Optical alignment pathfinder 2



- Purpose of OAP2
 - Engineering unit pathfinder
 - Development tool
 - Alignment and bonding
 - Assess mirror distortion
 - Mount induced
 - Thermal induced
 - Test mirror quality
- OAP2 description
 - Separate P & S housings
 - 4 connecting bars
 - Stiff structure for 1-g tests
 - Uses titanium components
 - Reduce ΔCTE effects

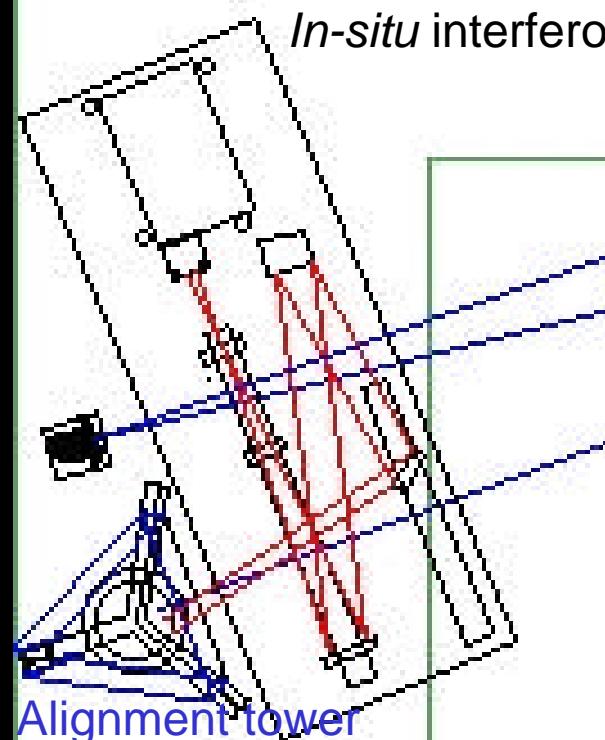


OAP2 alignment



GSFC alignment system

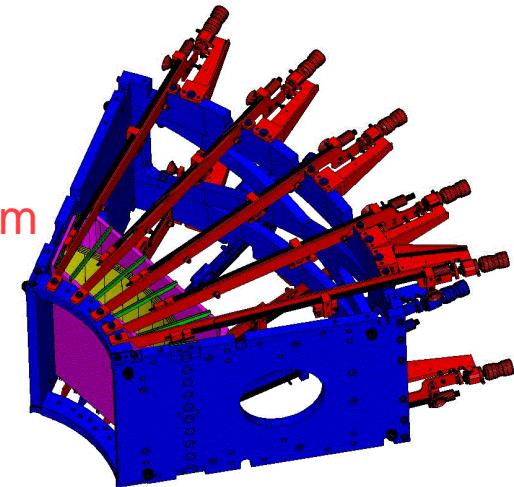
Centroid Detector Assembly (CDA)



Alignment mechanism

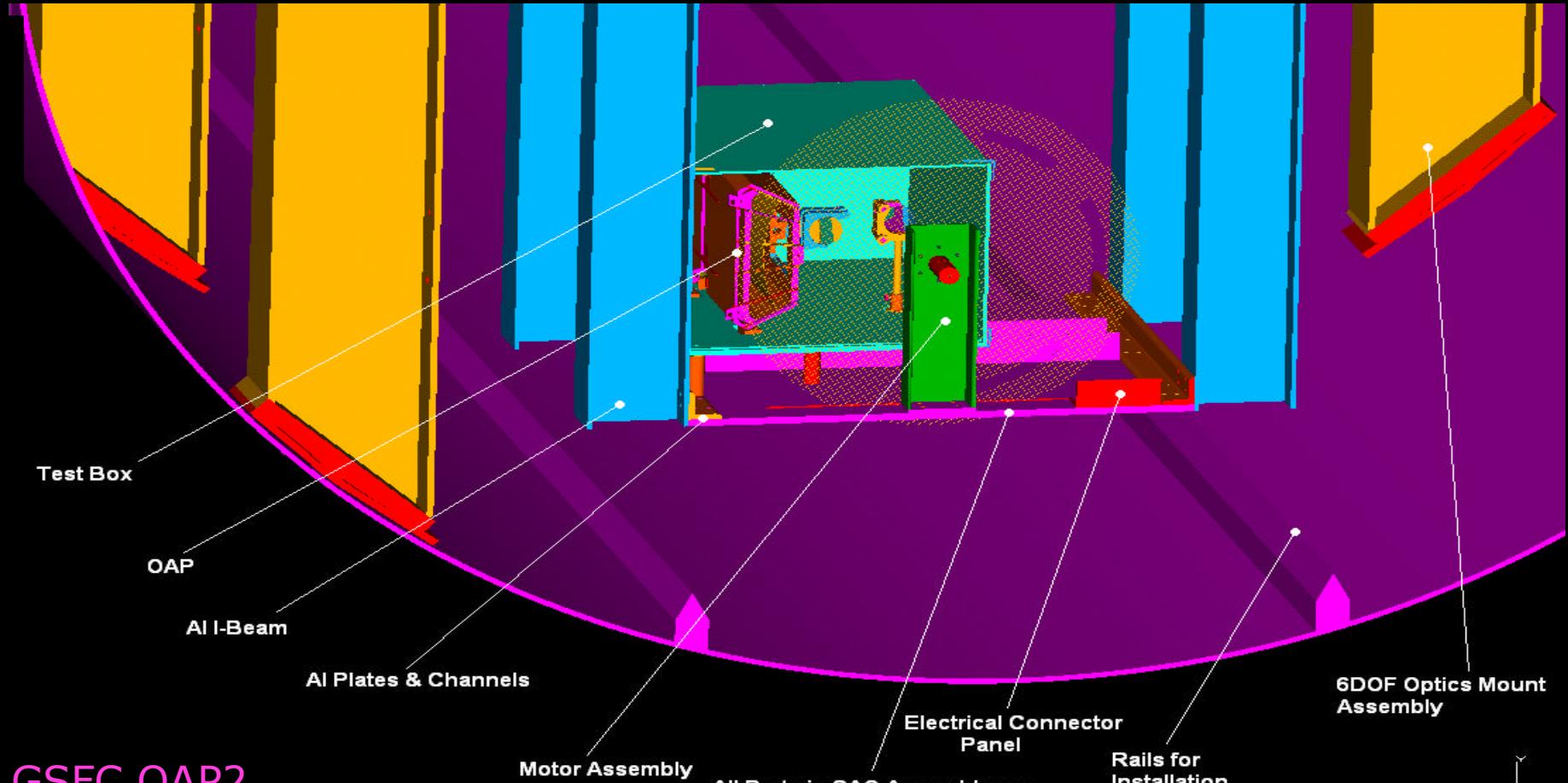
OAP1 (Al housing)

OAP2 (Ti housing)





OAP2 interface



GSFC OAP2
SAO box, aperture drive, I/F

X-ray testing Constellation-X optics at MSFC's 100-m facility
Optics for EUV, X-Ray, and Gamma-Ray Astronomy
2003 August 5-7, San Diego, California, USA

SPIE Conference 5168
Paper 34
Slide 10



OAP2 thermomechanical model



RESULTS: 10- B.C. 8.0 DISPLACEMENT 19.0N-EDGE-1
DISPLACEMENT = 2 MIN:-2.14E-03 MAX: 1.06E-02
FRAME OF REF: LOCAL_10

/usr3/people/daviss/ms7/OAP2fb.mf1

VALUE OPTION:ACTUAL

1.060-02

9.290-03

8.020-03

6.750-03

5.480-03

4.210-03

2.940-03

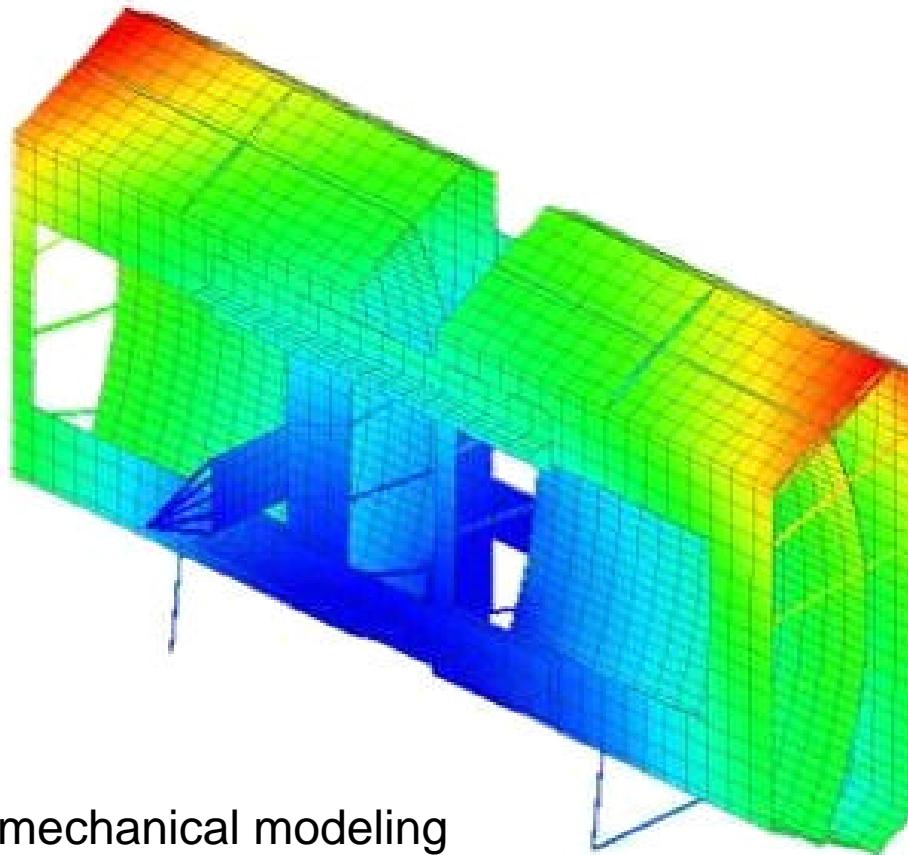
1.670-03

4.040-04

-8.660-04

-2.140-03

1



SAO thermal and mechanical modeling

X-ray testing Constellation-X optics at MSFC's 100-m facility
Optics for EUV, X-Ray, and Gamma-Ray Astronomy
2003 August 5-7, San Diego, California, USA

SPIE Conference 5168
Paper 34
Slide 11



OAP2 thermal sensitivity



Thermal Error Term	Sensitivity (arcsec/°C)	Requirement (°C)	HPD budget (arcsec)
Thermal Soak	0.3	1.0	0.30
Axial Gradient (Z)	0.2	0.5	0.10
Vertical Gradient (X)	1.5	0.5	0.75
Transverse Gradient (Y)	7.3	0.1	0.73
Epoxy Bi-layer effects	1.0	1.0	1.00
RSS all thermal errors			1.48



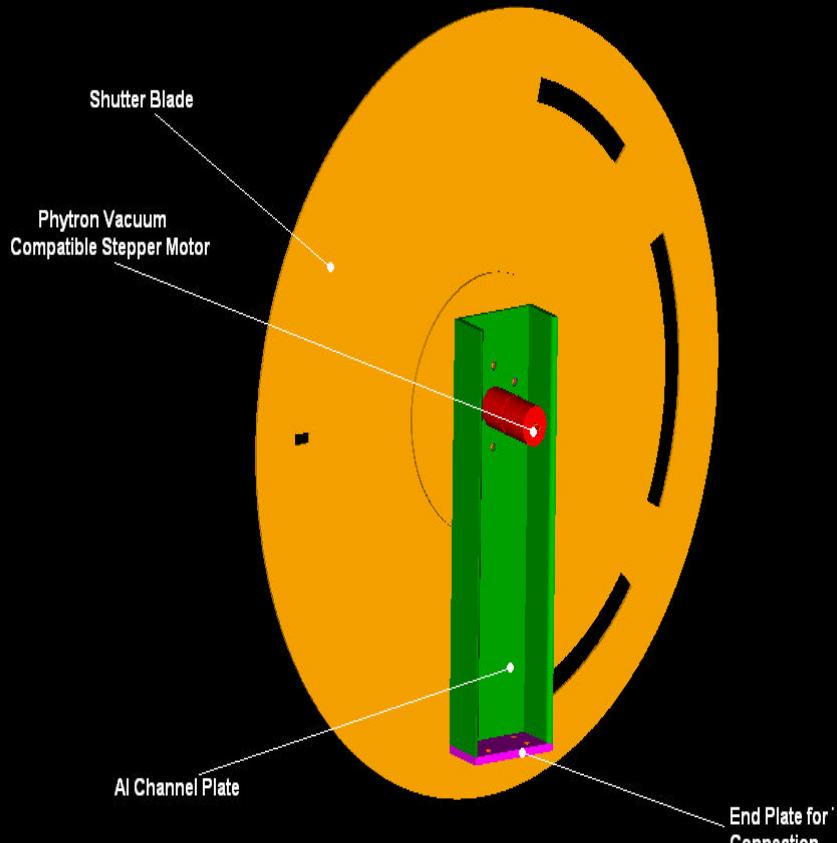
OAP2 thermal control system



- Thermal box
 - 6-sided aluminum
 - 2 strip heaters per side
 - Multi-layer insulation (MLI)
- Electronics
 - 3-zone temperature control
 - MINCO™ controllers
 - RTD sensors
 - Temperature monitors
 - 30 thermistors (total)
 - Thermal box and OAP2
 - SENSORAY™ data-acquisition boards
 - Data-acquisition computer



OAP2 aperture wheel



SAO aperture wheel

- Aperture wheel
 - Annular apertures
 - 50° , 40° , and 30°
 - Limit azimuthal size
 - 2° , 4° , or 6° subapertures
 - Sample azimuthally
 - Aperture-wheel motion
 - 1000 steps/rev (0.36°)
 - 20 step/rev Phytron™ stepper motor
 - 50:1 planetary gear box
 - Hall-effect home sensor
 - Intelligent Motion Systems™ indexer (in rack)



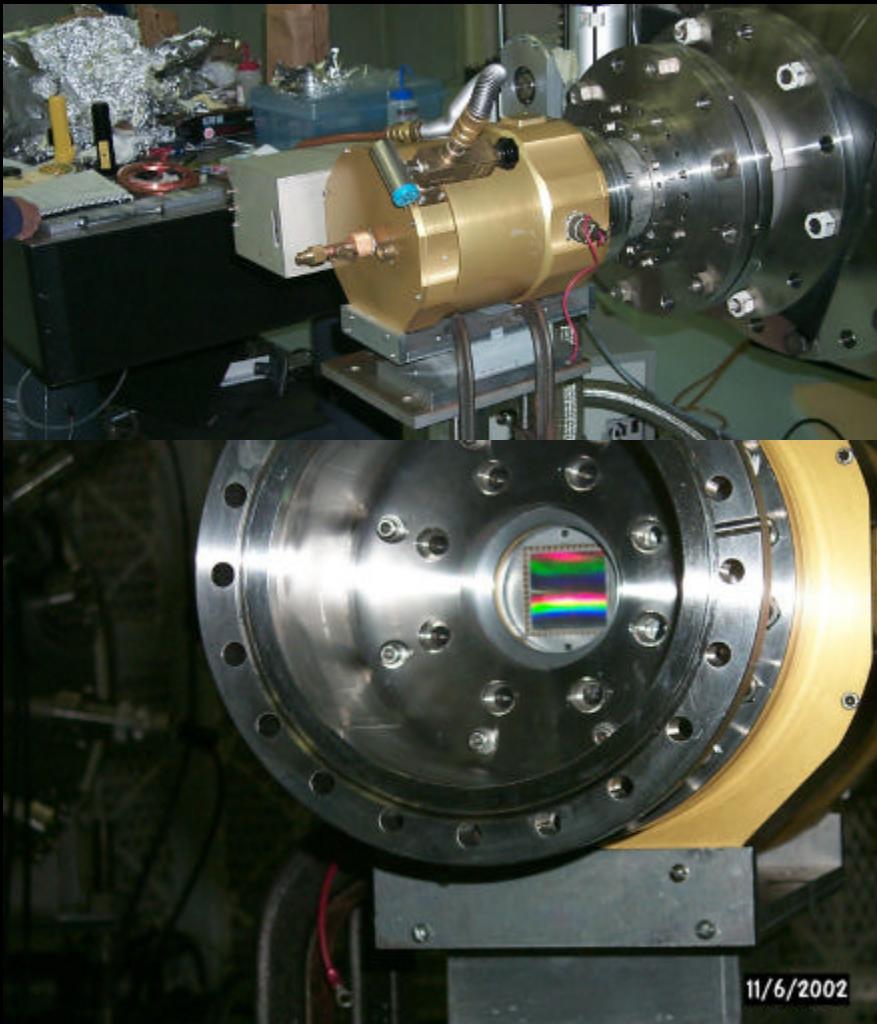
X-ray sources



- Electron-impact sources
 - Trufocus hard-x-ray source
 - High-energy source
 - 125 kV peak
 - Trufocus & Kevex sources
 - Medium-energy sources
 - Be window $\Rightarrow > 4$ keV
 - 50 kV peak
 - 1 mm to < 0.2 mm spot
 - Manson source
 - Low-energy source
 - Windowless, 15 kV peak
 - 1 mm spot
 - 2 arcsec @ 100 m



X-ray CCD detector



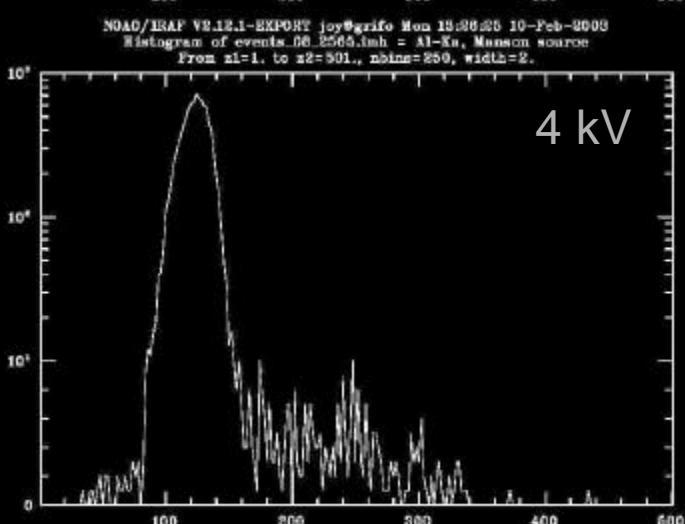
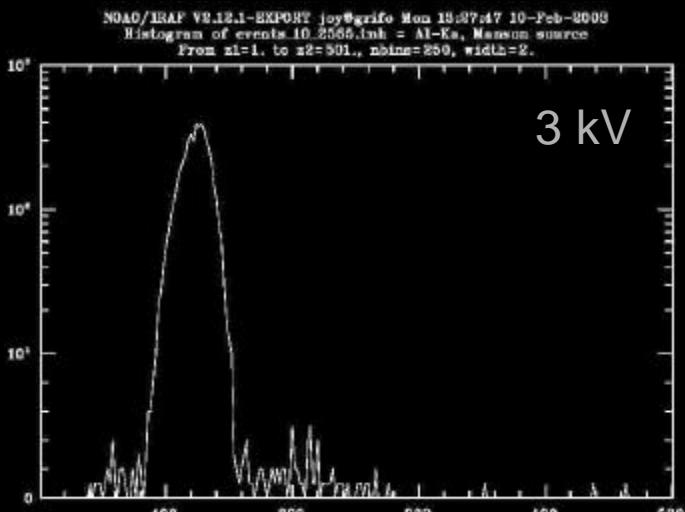
- Advantages for testing
 - Large field of view
 - 37-mm (1.5-in) square
 - 13 arcmin @ 10 m
 - 2048 × 2048 pixels
 - Very good spatial resolution
 - 18- μ m square pixels
 - 0.4 arcsec @ 10 m
- Disadvantages for testing
 - Front-illuminated device
 - Little response < 0.8 keV
 - Slow read-out electronics
 - 100-s read-out
 - Bad for photon counting

X-ray testing Constellation-X optics at MSFC's 100-m facility
Optics for EUV, X-Ray, and Gamma-Ray Astronomy
2003 August 5-7, San Diego, California, USA

SPIE Conference 5168
Paper 34
Slide 16



Source-detector performance



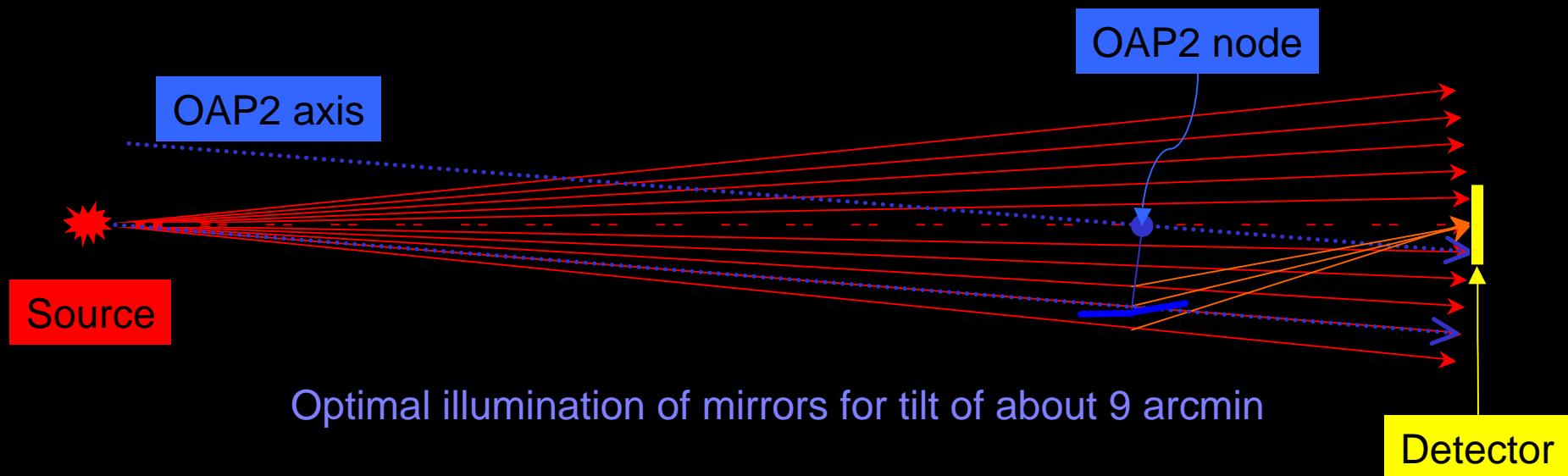
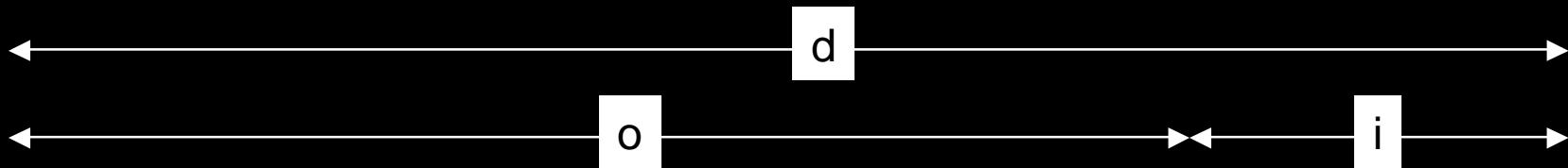
- CCD camera
 - Slow read-out electronics
 - Charge collection
 - Require spectral purity
 - 97 ke - (356 keV) well
- Manson source (Al anode)
 - Al-K α @ 1.49 keV
 - HV between 3 and 4 kV
 - Al filter (20 μm)
 - Filters above Al-K edge
 - Block visible light
- Measured characteristics
 - 10–40 ct/(cm 2 s mA)



Optics alignment



For source-to-detector distance $d = 103000$ mm,
image distance $i = 9226.5$ mm for focal length $f = 8400$ mm





OAP2 test rehearsals



- Purposes
 - Rehearse installation, alignment, and operation.
 - Develop and document procedures.
 - Exercise hardware in vacuum environment.
 - 6-DoF mount, aperture wheel, thermal control.
 - Practice performance testing and data analysis.
 - Beam finding, focus finding, on-axis and off-axis imaging
 - Subaperture sampling with aperture wheel
 - Intrafocal (ring segment) images
- Plans
 - Conduct rehearsal with OAP2 surrogate by September.
 - Refine procedures in preparation for OAP2 test in 2004.